High-Rate Ka-Band Modulator for the NISAR Mission

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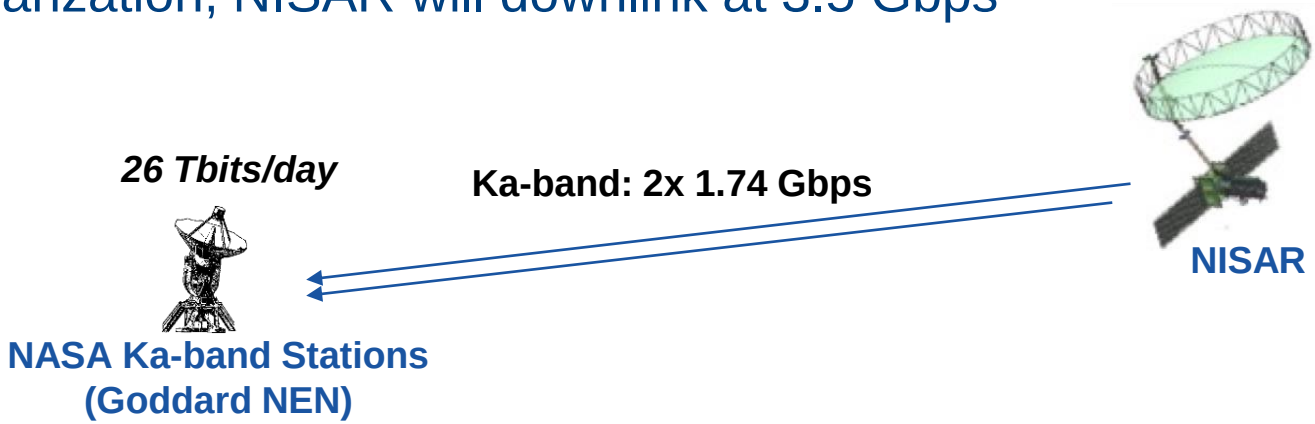
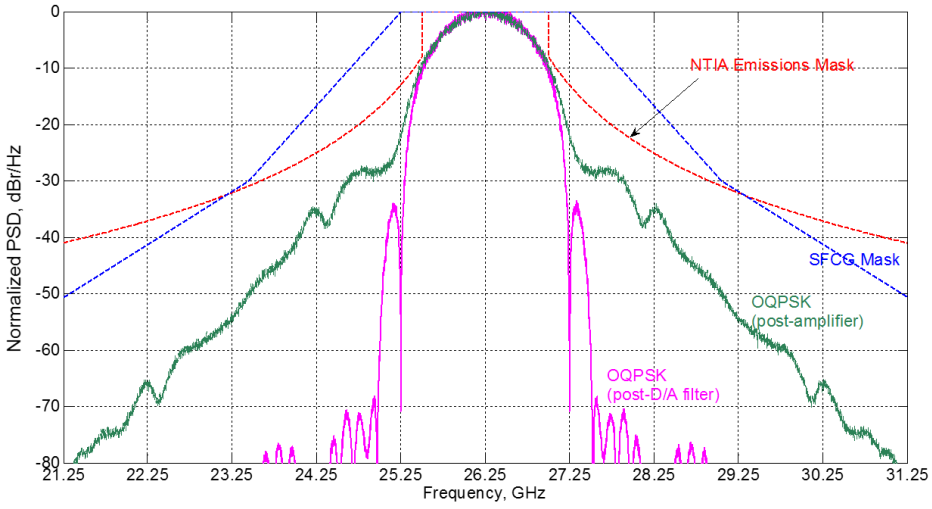
NISAR Mission

- The NASA ISRO Synthetic Aperture Radar (NISAR) will use dual-band SAR to study the dynamics of ice flow, crust deformation, and landscape change in unprecedented detail
- To achieve this, NISAR will produce massive data volumes (>26 Tbits per day) and require Gbps-class downlinks
- With no commercially available flight transmitters capable of >1 Gbps and at an acceptable NASA Technology Readiness Level (TRL), JPL has developed the Universal Space Transponder – Ka-band Modulator (UST-KaM)
- Utilizing two UST-KaM units transmitting 1.74 Gbps on each polarization, NISAR will downlink at 3.5 Gbps



UST-KaM Communication Architecture

- UST-KaM transmits 2 Gbps coded data rate while complying with the NTIA 1.5 GHz band allocation for near-Earth Ka-band (25.5-27 GHz)
- Offset-QPSK modulation with baseband filtering
  - 1 GHz RF low-pass filters on I/Q as well as RRC digital pulse shaping
  - Bandwidth efficient while still offering good Eb/No performance
  - Offset I and Q transitions is resilient to spectral regrowth by saturated amplifiers
- CCSDS LDPC 7/8 encoding
  - High-rate code minimizes overhead while still providing ~8 dB of coding gain
  - Synchronizes with CCSDS AOS framing, sharing single sync marker
  - Pseudo-randomizer to ensure bit transition density



Simulated Spectrum of Filtered OQPSK pre- and post- Saturated Amp

UST-KaM Specs

TX Specs	
Frequencies	Ka-band (25.5-27 GHz)
Bandwidth	< 1.5 GHz
Coded Data Rates	500, 1000, 2000 Gsps
Modulations	QPSK / OQPSK with Custom Baseband Analog Filtering
Digital Pulse Shaping	Root Raised Cosine (Optional)
Channel Coding	LDPC with Rate 223/255 (~7/8)
RF Output Power	+12 dBm

Environmental Specs	
Flight Allowable Temperatures	-20° to +50° C
Mechanical Environments	>15 grms Random Vibration >2000 g Shock
Radiation	50 krad

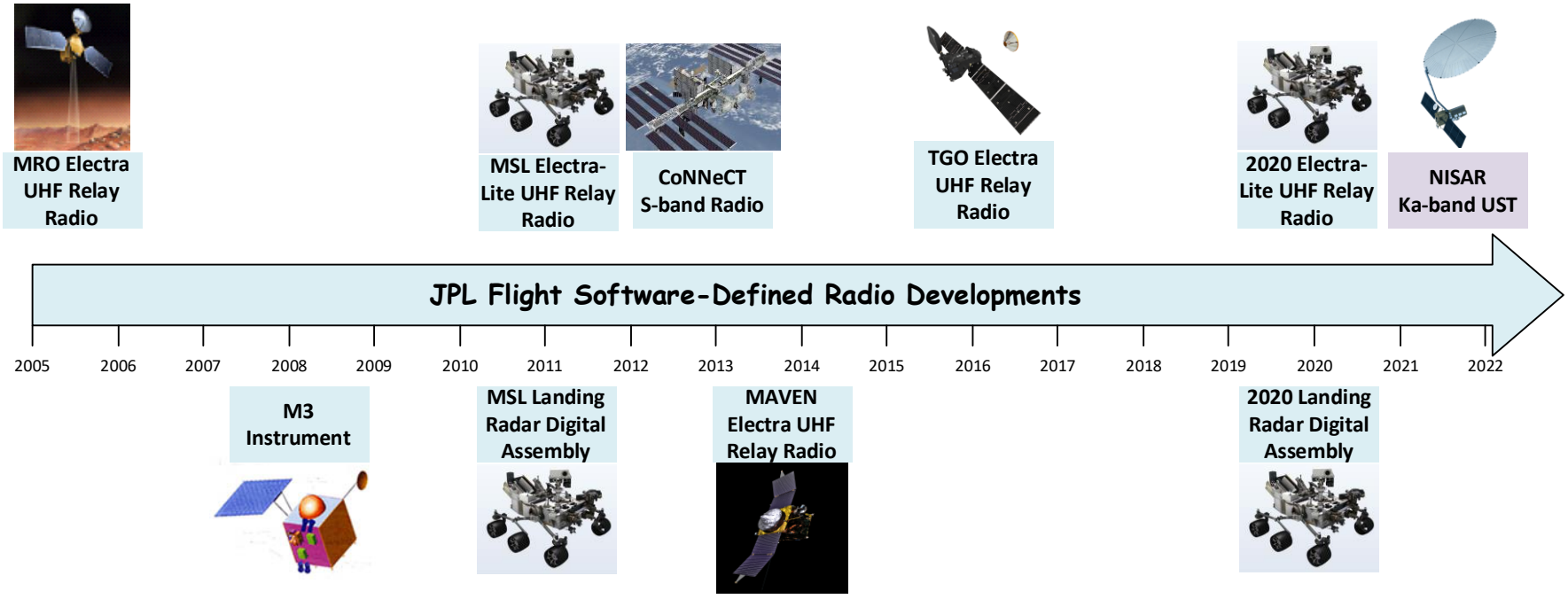
Interface Specs	
Mass	4.5 kg
Power Consumption	40 W TX Mode 20 W Standby Mode
Cmd/Tlm Interface	1553, RS-422, or Spacewire
High Speed Data Interface	TLK WizardLink SERDES (up to 2 Gbps)
Power Interface	22-36 V Unregulated Bus
Dimensions	25 x 20 x 11 cm (L x W x H)

Universal Space Transponder Radio Family

- The high-rate Ka-band Modulator developed as part of JPL's Universal Space Transponder (UST) product line
- UST is JPL's next generation software defined radio family, designed to meet the following goals:
  - Modular hardware and digital architectures that provide flexibility to meet a large variety of telecom, navigation, and radio science needs with a single radio platform
  - Expandability to handle multiple RF links (UHF, S-, X-, or Ka-band), allowing a single unit to support both relay and direct-to-Earth communications for near-Earth or deep space missions
  - Significantly higher bi-directional data rates than current deep-space radios to increase mission return data volumes
  - Sufficient digital resources to enable advanced modulations, FEC coding, protocols, and navigation techniques
  - In-flight reprogrammable to allow new functionality or bug fixes during any mission phase
  - Frequency agility to increase flexibility in channel assignments or to avoid EMI

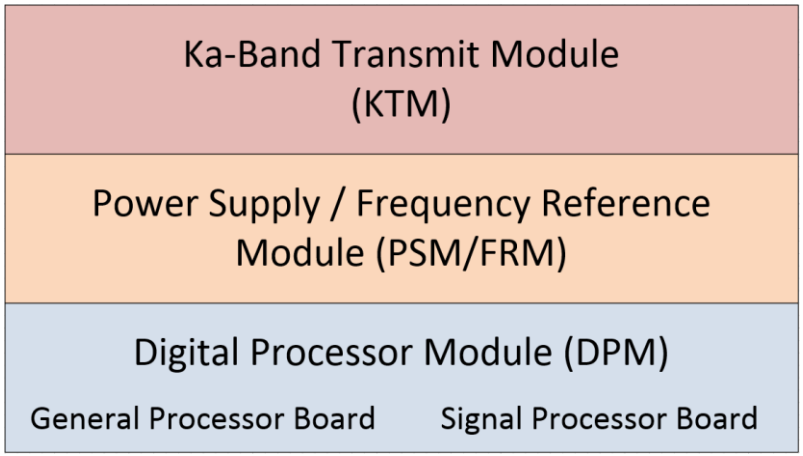
UST-KaM Heritage

- UST-KaM leverages design features from JPL's previous flight SDRs
  - Stacked module configuration with separate digital, power, and RF modules
  - One-time programmable Housekeeper FPGA and PROM for reliable Safe Mode
  - Xilinx FPGA with in-flight reprogrammable firmware for modem processing
  - SPARC microprocessor with in-flight reprogrammable Application Software



UST-KaM Hardware Architecture

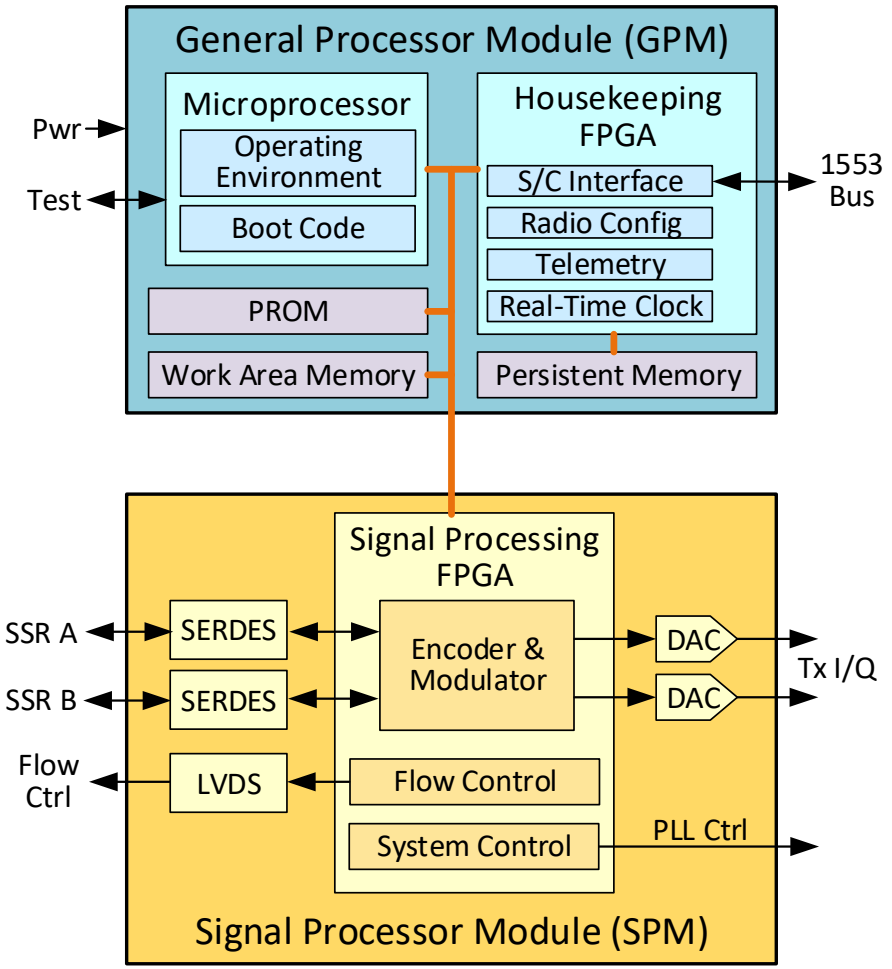
- UST KaM uses a modular architecture with three modules or “slices” that are connected by coax cables and a single flex harness in a rear raceway
- The bottom digital and power modules are common to any UST variant, with the needed RF modules stacked on top



- Ka-Band Transmitter Module (KTM)
  - Modulates I/Q baseband signals onto Ka-band RF transmission
  - Provides 2 GHz reference for DACs in DPM
- Power Supply / Frequency Reference Module (PSM/FRM)
  - Converts primary power to regulated secondary voltages
  - Provides TCXO frequency reference to other modules
- Digital Processor Module (DPM)
  - Provides all the digital interfaces with the spacecraft
  - Performs baseband processing and modulation of transmit data
  - Unit housekeeping functions and telemetry collection

Digital Processor Module (DPM) Architecture

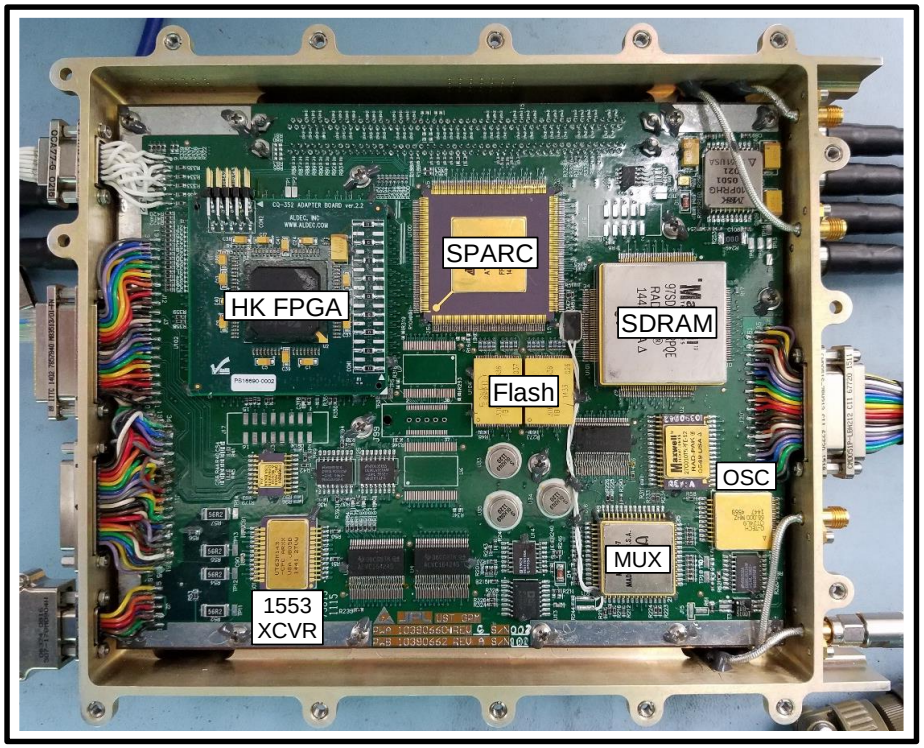
- Compliant with NASA Space Telecom Radio System (STRS) standard for software defined radios
- General Processor Module (GPM)
  - Command and telemetry over MIL-STD-1553B, RS-422, or Spacewire interface
  - Analog telemetry collection (voltages, temperatures, etc.)
  - Provides storage and management of software and firmware images for all reprogrammable DPM elements
  - Configuration and scrubbing interface for Xilinx Virtex-5 FPGA on SPM
  - Overall radio management, including PSM and RF module control
- Signal Processor Module (SPM)
  - High-speed interfaces to Spacecraft SSR via TLK2711 SERDES transceivers
  - Virtex-5 FPGA for modem processing
  - In-flight reprogrammable
  - High-speed DACs for I/Q data
  - TX frequency synthesizer programming



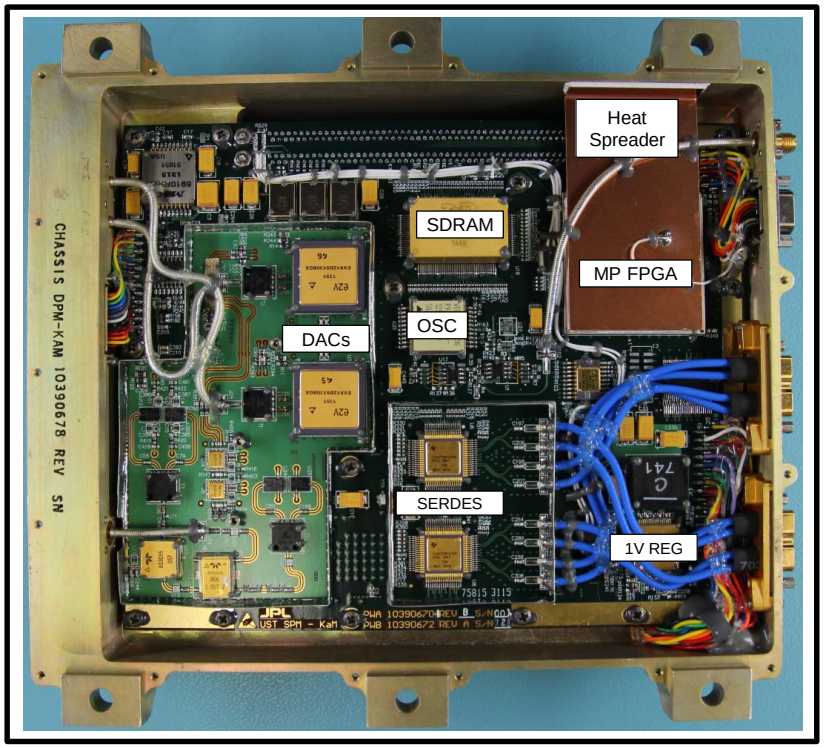
DPM Details

- Top side of the DPM
  - Housekeeper RTAX FPGA
  - SPARC Microprocessor with SDRAM runtime memory and flash for SW/FW storage
  - 1553 and SpaceWire/RS-422 interfaces
  - Analog MUX and telemetry ADC
  - PSM and RF module control outputs

- Bottom side of the DPM
  - Xilinx Virtex-5 Modem Processor FPGA
  - Xilinx power sequencing/distribution
  - High-speed Transmit I/Q DACs
  - SSR SERDES transceivers
  - SDRAM buffer memory



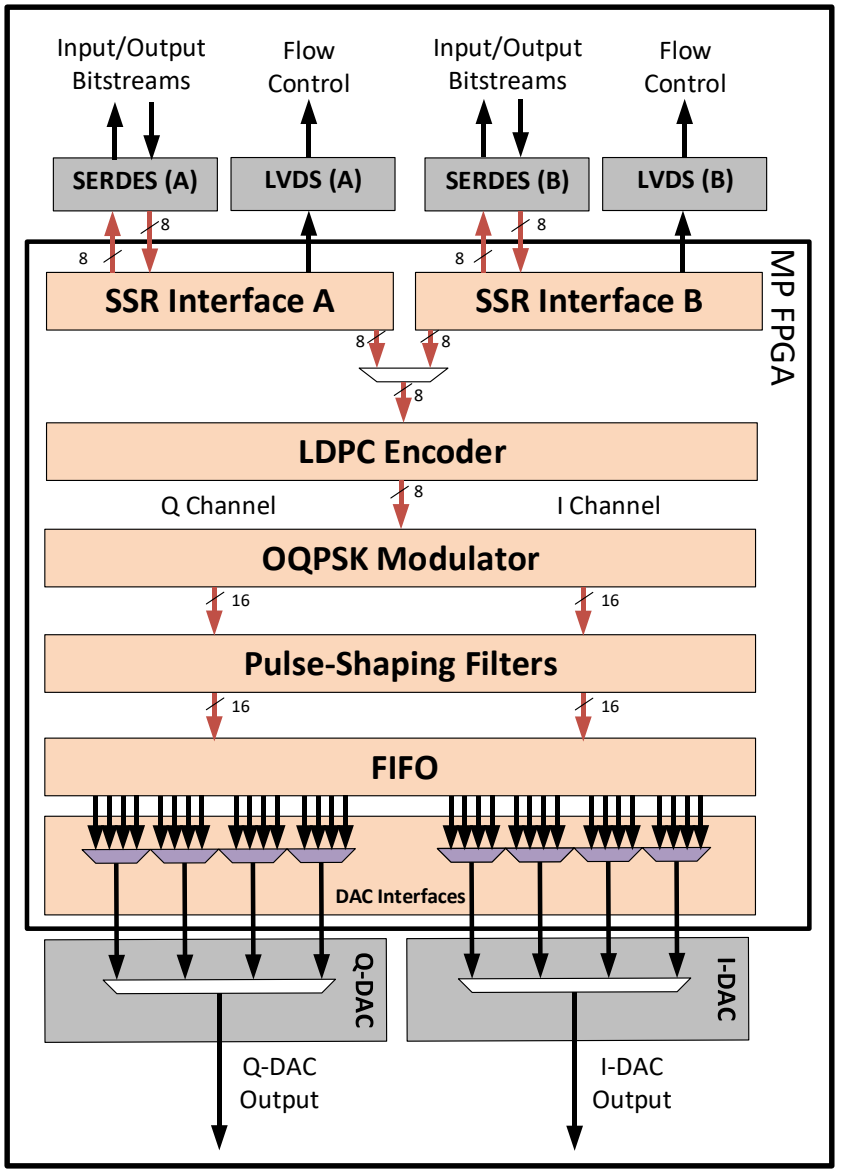
EM DPM Slice Top (GPM PWA Side)



EM DPM Slice Bottom (SPM PWA Side)

Modem Processor FPGA

- All DSP implemented in Xilinx Virtex-5 Modem Processor (MP) FPGA
- High-speed processing with 125 MHz main clock
- 2 Gbps,16-bit parallel SSR interface with 8b/10b encoding and K-codes for AOS frame synchronization
- Parallel CCSDS (860,7136) low-density parity check (LDPC-7/8) encoder with pseudorandomizer and ASM attachment
- Parallel 16-bit OQPSK I/Q modulator with 2 complex samples per channel symbol at 2 Gbps
- Parallel Root-Raised Cosine (RRC) pulse-shaping filter for inter-symbol interference (ISI) reduction
- High-speed interface logic to 12-bit DACs with built-in 4:1 multiplexer



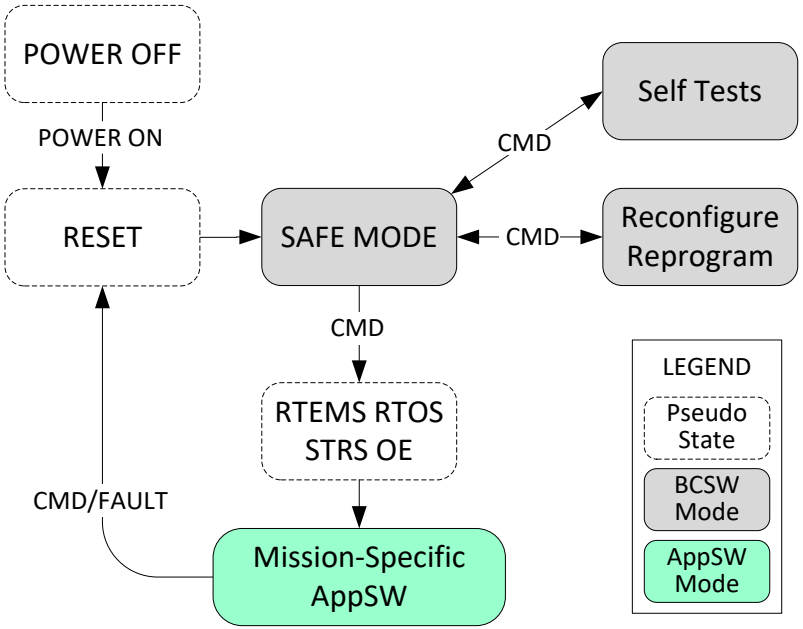
Software

Boot Code Software (BCSW) provides a "Safe Mode" – always available and loaded on power-on or reset from one-time programmable rad-hard PROM

- Telemetry collection and reporting
- Command and control via 1553
- Basic commands for AppSW loading
- Accepts new FW/SW images over 1553 and manages flash storage

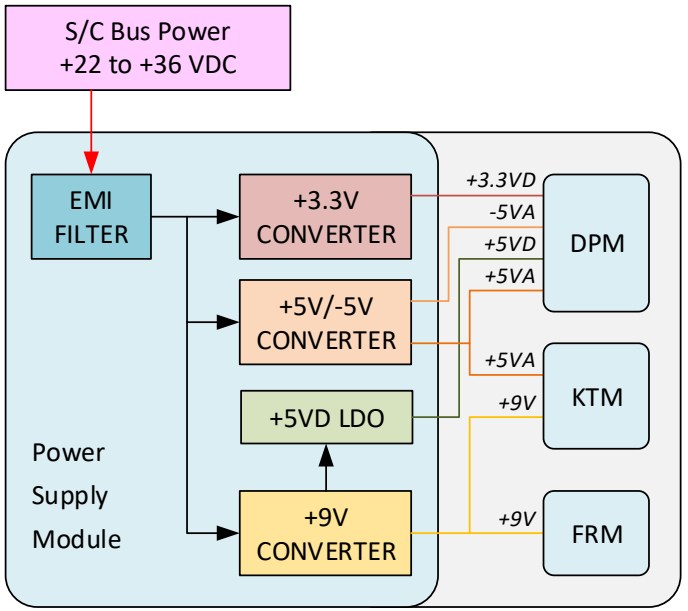
Application Software (AppSW) provides mission-specific functionalities on top of basic BCSW functions – loaded from image in flash memory

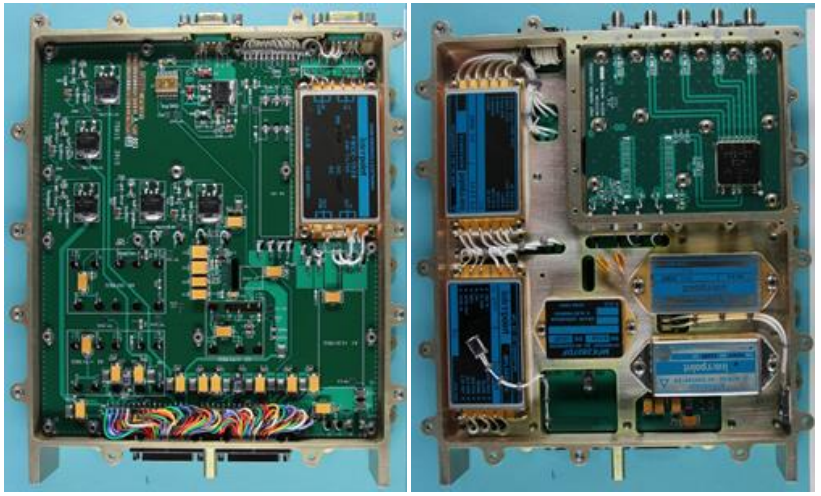
- Programs and initializes the Modem Processor FPGA and configures modem parameters
- Configures DACs, memories, and SSR data interfaces
- Real-time amplitude adjustments to compensate for temperature variations



Power Supply Module (PSM)

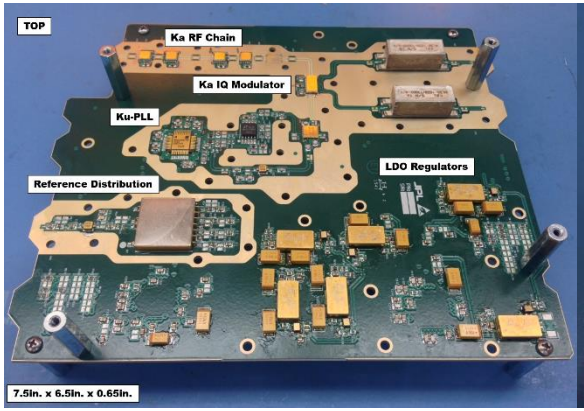
- Accepts unregulated 22 to 36V bus power input from Spacecraft
- Provides regulated secondary DC power to other UST modules
- Design is based on a heritage architecture, with the spacecraft power bus passing through an EMI filter and then distributing to various DC/DC secondary converters
- Additional PWB in dedicated cavity for TCXO frequency reference distribution
- Split chassis design with DC/DC converters and the frequency reference PWB on one side of a common floor and the power PWB on the other side



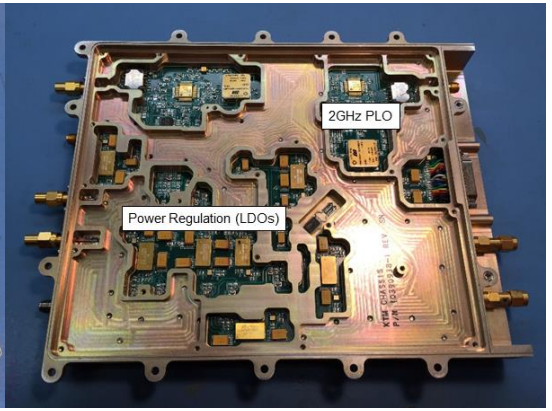


Ka-Band Transmitter Module (KTM)

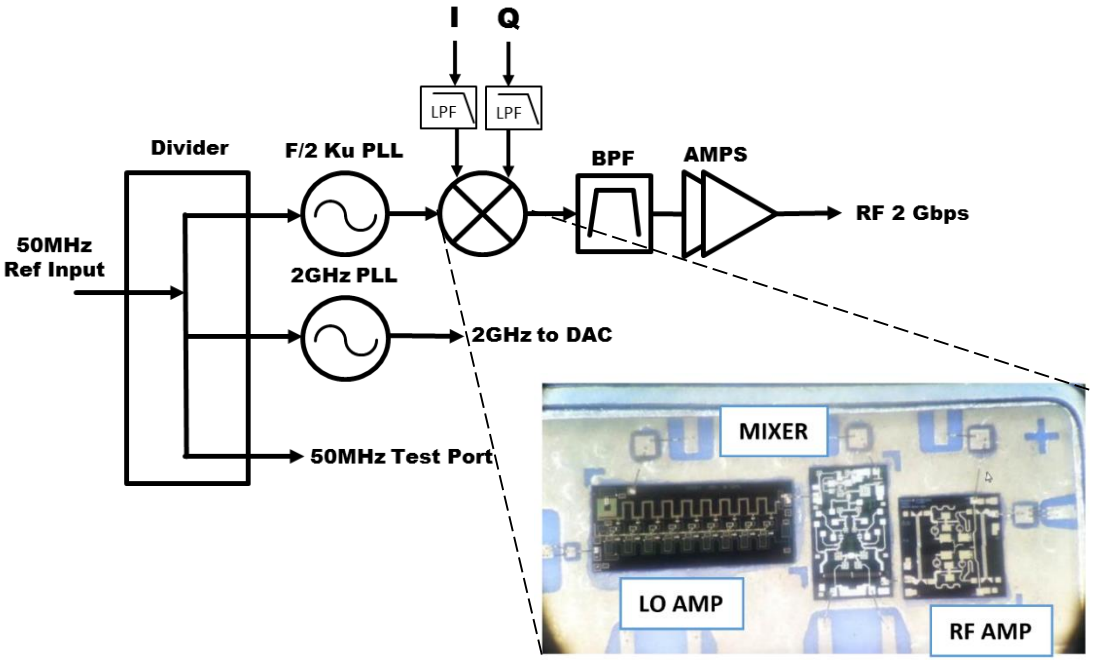
- Ka-band output carrier modulated by in-phase and quadrature (IQ) digital waveforms from the DPM
- Custom multi-chip module (MCM) sub-harmonic IQ modulator eliminates need for Ka-band VCO
- Analog baseband filtering for data side-lobe rejection
- Transmit output filtering for harmonics suppression
- On-board frequency synthesizers for DPM high-speed clock and KTM modulator LO
- All surface-mount technology (SMT) hybrids for package-size reduction and lower Ka-band interconnect losses
- Internal clamshell covers to reduce signal crosstalk



Ka-band Transmitter EM PWA (Top View)



Ka-band Transmitter EM Assembly (Bottom View)

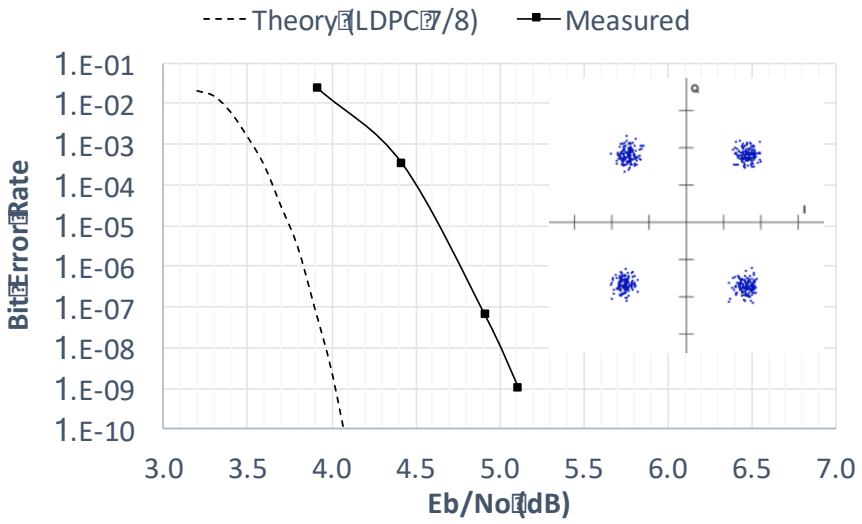


Custom MCM IQ Modulator

Engineering Model Test Results

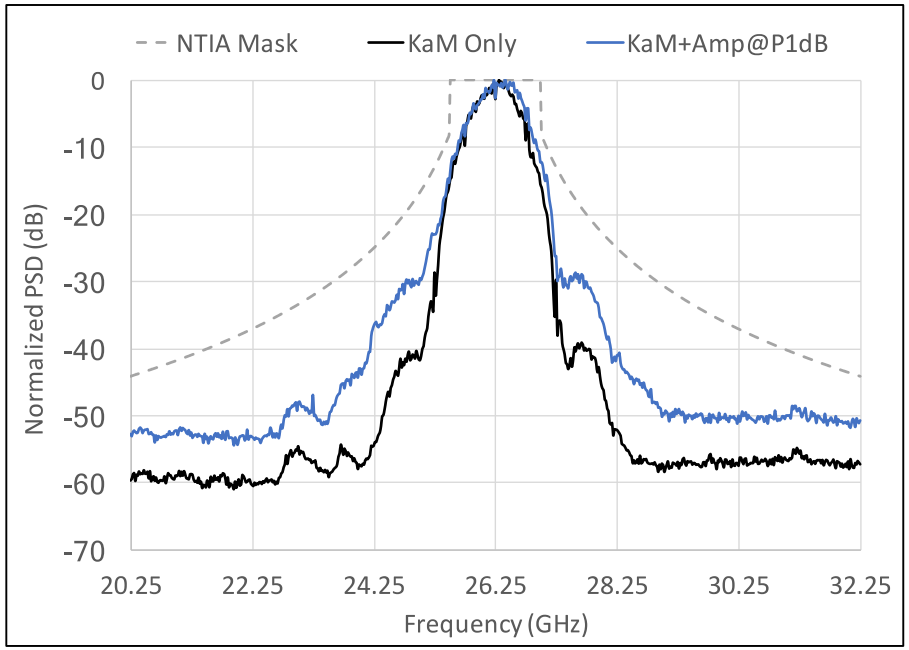
- NASA TRL 6 demonstrated via testing an engineering model in 2016, including three-axis dynamics, thermal vacuum, and EMI/EMC testing
- All specification met across the allowable flight temperature range
- Compatibility demonstrated with commercial, high-rate ground-station receivers from Zodiac and ViaSat

Parameter	Units	Spec.	Meas.
DC Power Consumption (Transmit Mode)	Watts	< 50.0	40.9
DC Power Consumption (Standby Mode)	Watts	< 24.0	19.9
RF Output Power	dBm	> 12.0	12.4
Carrier Frequency	GHz	26.25	26.25
Carrier Phase Noise (1 kHz – 10 MHz)	deg, rms	< 3.6	3.1
Coded Data Rate	Gbps	2.0	2.0
Phase Imbalance	deg	< 5.2	3.5
Amplitude Imbalance	dB	< 1.1	0.4
Spurious Outputs	dBc	< -60	None

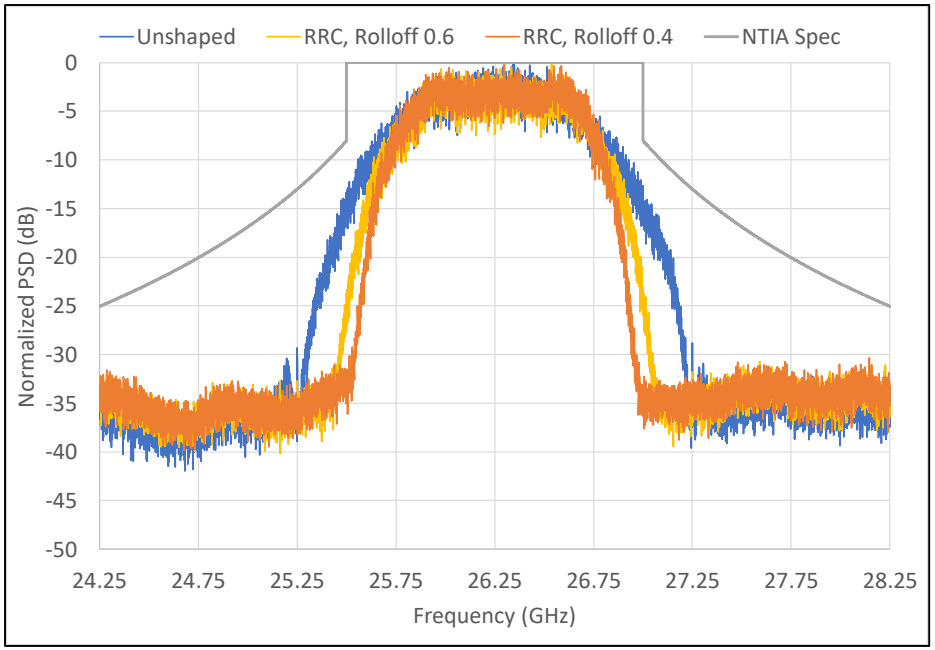


Spectral Compliance and Pulse Shaping

- Consistent with simulations, NTIA compliance was maintained with a saturated, external RF amplifier
- Additional testing with RRC pulse shaping produced improved spectral efficiency for cases without significant saturation



Measured Spectrum pre- and post- Saturated Amp



Measured Spectrum with Digital Pulse Shaping

Future Plans

- The NISAR project is currently in the flight hardware build phase with a scheduled launch for late 2020
  - Three flight models of the UST-KaM are currently being assembled at JPL
  - Flight models will be integrated in 2018 and complete a proto-flight qualification program in 2019
  - JPL will likely select and work with an industry partner on builds for any future missions
- Additional development planned for higher-rate UST-KaM operational modes to achieve ~4 Gbps transmission rate per unit
  - Operating dual SERDES inputs simultaneously for faster transfer from SSR
  - Higher-order modulations such as 16-APSK could increase date throughput at the cost of link SNR
  - Increasing channel symbol rate to 1.3 Gsps with RRC pulse shaping to maintain spectral compliance

Acknowledgements

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